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A theory for treating visual vertigo due to optical flow

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Running Title: Treating Visual Vertigo Due To Optical Flow

ABSTRACT

It has been suggested that dizziness patients with visual vertigo benefit from the addition to their standard vestibular rehabilitation of optic flow stimuli and exercises involving visuo-vestibular conflict[1,2]. One approach to do this is using virtual reality training[3-6]. In this paper we propose a simple framework based on a hypothesis that the degree of dizziness depends on the offsetting between the destabilizing effect of optical flow and the stabilizing effect provided by stationary objects in the visual field. We define a total destabilizing potential (TDP) which is the ratio of the destabilizing effect over the stabilizing effect. The approach is to gradually increase the patient's tolerance of a higher TDP through exercises that may be described as an inverse of the traditional gaze stabilization exercises for vestibular rehabilitation. The theory proposes that an important ingredient in virtual reality training is to incorporate a stationary anchor to help synchronizing the visual sensory to vestibular and somatosensory inputs. The scheme can also be adopted economically with computer generated imagery or used by patient in certain every day environments. The proposed TDP may be used as a parameter for measuring the degree of visual vertigo quantitatively. In addition, the theory also suggests a strategy of reducing the destabilizing potential to manage the visual vertigo condition.

1. Introduction

Our hypothesis is derived from a patient's case history. The patient, the first author (CPC), was then a 59-year old male professor who experienced a BPPV attack in October 2004. The BPPV was cured through one session of Canalith Repositioning Procedure but visually induced space-motion discomfort continued for 18 months almost without break. The dizziness affected his daily life significantly. Among many impacts, he was unable to stand in front of a class to teach, or to view PowerPoint presentations from close distance. He also had troubles attending meetings, scrolling on computer screens, going into grocery stores, buffet restaurants or airport terminals, driving on roads with stop signs, and visiting friends' homes if there were colorful or complex interior decorations. Dizziness often struck when he lowered his head to sign credit cards or letters or looked at a keyboard; sometimes he felt his eyeballs were locked to the looking-down position such that he could not raise his head back to normal level.

Extensive diagnoses did not reveal evidence of migraine or any other specific causes, except a CT scan and mild conduction hearing loss indicated superior canal dehiscence[7] on the opposite side as BPPV, but because there was no Tullio or any sound or pressure induced symptoms, it may also indicate a thinning condition[8]. He underwent about a dozen sessions of vestibular rehabilitation and one session of virtual reality testing with no appreciable effect.

Starting March 2005 he kept a daily log of a subjective dizziness index that ranges from 0 up to 3.0, which indicates severe dizziness including oscillopsia. Three index values are recorded each day: the highest and lowest during day time and one night value at home, which was usually the daily minimum. Day values are usually above 1.0, and night values are often slightly below 1.0 when the patient felt only mild

symptoms. Notes on events or environments that might affect the level of dizziness

were also recorded every day. The log was calibrated frequently to compare current and

all past recordings to maximize consistency. His experience eventually allowed him to

predict the degree of dizziness that is likely presented in a given environmental condition.

This paper describes this experience and proposes a hypothesis that may be used to

measure and treat visual vertigo.

2. Empirical Base

The consistent experience that eventually emerged suggests that, when the

visual environment was surrounded by large stationary structures such as close-by tall

buildings, there was usually less dizziness than areas surrounded by lower buildings.

This difference became larger when the scene became busier due to the presence of

crowds of people or cars. For example, in different parts of the campus, the feeling of

dizziness was consistently different even when there were about the same large number

of students moving around. The contrast is schematically illustrated in Figure 1. Similar

differences occurred during day time walking in busy city streets with and without tall

buildings and lampposts, and in busy freeways with and without sound walls, close by

elevated terrain, and large overpass structures. It is well known that some visual

dependent patients feel dizzy in wide open spaces. However, the key point here is that

when crowds were absent the patient did not feel much difference between areas

surrounded by tall buildings and areas that were not. Wide open spaces with green

grasses or by the ocean were the preferred places for the patient where he could find

breaks from the persistent dizziness. The harmonious landscape appeared to provide

the less-disturbing, stationary environment. But when crowds were present, the more

open the space the more uncomfortable he felt.

In early January 2006 after reading literatures suggesting that optokinetic stimuli may help[2-6], he attempted a stimulation exercise entailing trying to watch fast moving trains that he knew would make him very uncomfortable. Up to that time he had been avoiding eye contact with TV screens because faster scenes can easily trigger intensified dizziness. After mentally preparing himself, he opened his eyes for a fraction of a second to glimpse the passing train that was traveling at approximately 50 miles/hour. He felt that he was subject to a disturbing force and responded immediately trying to keep himself steady, but the short duration did not cause dizziness or other uncomfortable feeling. He then repeated the exercise, opening his eyes briefly several times during the 7 to 8 minutes that took the freight train to pass. Each opening lasted no more than half second and he shut his eyes just before dizziness was to strike.

Prior to the train viewing exercise the patient went through a session of a virtual reality experiment at the Virtual Environment & Postural Orientation Laboratory at the Rehabilitation Institute of Chicago in December 2005. The exercise involved viewing a 3D image of a rotating temple with a pair of goggles. He was supposedly totally immersed inside the 3D temple with a full field of view being the temple, but the top edge of the goggles blocked the upper part of the view resulting in a dark upper boundary that frames the field of view. When the temple rotated he felt the destabilizing effect that was forcing him to fall from the platform, but he was able to use the sight of the upper frame as a support to resist the forcing by the sight of the rotating temple. He eventually fell out of the platform after durations that were similar to those for people with normal vestibular functions.

In viewing the passing train as a rear seat passenger from inside the taxi in that early January 2006 morning, the frame of the front window including the interior of the car apparently became the support that enabled him to resist the disturbing force of the

sight of the moving train. Thus, it appears that the stationary frame helped him as an anchor to resist the destabilizing effect of the visual perturbation. He practiced the train viewing exercise several more times in the first half of January 2006, whenever there was an opportunity – usually when he was a passenger in his car pool which normally crossed a railroad crossing twice a day. The duration of each eye opening was around one second. He closed his eyes sooner whenever he felt too uncomfortable.

In mid-January 2006 he took a sabbatical leave to do research at a university in Taiwan. He took rapid transit in Taipei daily. The subway stations provided an opportunity to continue his train viewing exercises. Typically inside a station the well lighted area around the platform provides a large and pleasant view of stationary surroundings, imbedded in which the rapidly moving train provides the stimulus. He tried to look at each train that is entering or leaving the platform, open his eyes as long as he can tolerate. The stationary surroundings provided the anchoring effect that countered the destabilizing effect from the moving train. He also looked from inside a train outward as the trains are entering or leaving a station, thus each day he had several opportunities that he could exercise. The maximum duration of viewing increased from about 1-2 seconds in mid January to 2-3 seconds in late January, and 3-5 seconds in mid February. There were fluctuations of this duration and occasionally he found himself closing his eyes quicker to avoid triggering dizziness. By end of January he noticed that the dizziness frequency and intensity had both subsided, and the improvement continued so that by the end of March he felt, for the first time in 18 months of dizziness, that he is on the way to recovery. Figure 2 shows that the daytime averaged dizziness index has been around or above 1.0 from onset to the beginning of January 2006 when he started the train viewing exercise. It drops to below 0.5 in early February and to negligible values in late March. Since classroom teaching had always been the most

difficult challenge during his sickness, in May he returned to California to teach two

classes a day for 5 weeks to ascertain that his recovery was indeed real. He is now able

to view passing subway trains without any constraint but he is continuing the exercise

whenever opportunity presents.

3. Hypothesis

The case above suggests that the dizziness due to optical flow may be inversely

proportional to the effect of stationary noncomplex images in the field of view. If we

define a destabilizing potential (D):

$DP = D/S$,

where D is the destabilizing effect and S is the stabilizing effect, then a larger DP will

trigger more frequent or intense dizziness. The next question is to define D and S.

Figure 3a (left panel) is a schematic diagram indicating an *aiming* area A imbedded in a

background environmental area B, like a picture-in-picture TV. If the aiming area is a

sight of optical flow such as that produced by a long moving train, an approximation is to

let $D = A \times f(V)$ and $S = B$ where V is the velocity of the optical flow. In general V is a

three dimensional velocity field that may also vary with time, but for the simplest case of

linear constant velocity, $f(V)$ will be represented by a constant speed,

$DP = D/S = A/B \times V$.

While this simplification does not address the effect of depth of the focal plane and flow

variations, it is reasonable to assume that the magnitude of V is correlated with the effect

of $f(V)$. Namely, when there is a larger V, all effects (three-dimensional shear, curl,

divergence) tend to be larger.

One may further consider, based on empirical and heuristic logics, that the total

effect on a visual vertigo patient is DP integrated over the duration of exposure, i.e.,

TDP = $\int D/S \, dt$

$= t \times A/B \times V$ for constant *A*, *B* and *V*.

It is obvious that a patient will not suffer visual vertigo if either *t* or *A* or *V* approaches 0.

To develop a therapy, the patient will be subject to a lower value of *TDP* initially. This value would be determined subjectively by the tolerance of the patient or by equipments such as a dynamic posturography. The *TDP* can then be increased with the progress of the therapy by increasing either *t*, *A/B*, or *V*. For the train viewing case, the patient can only control t. In a laboratory or clinic environment, *A/B* and *V* can all be controlled. One example is to expand the size of *A* in Figure 3a as the therapy progresses.

This proposed scheme is, in a way, analogous to an inverse of the gaze stabilization scheme in the traditional therapy for vestibular rehabilitation. In the latter, the aiming area *A* is a small single object with slow relative motion such that the eyes can be trained to stay focused on the object, while the background environment is typically busy with fast optical flow or complex patterns (Figure 3b). The patient is being trained to stay with *A* while ignoring *B*. In the proposed scheme, *A* is the fast moving optical flow and *B* is stationary and noncomplex background. The patient not only does not ignore *B*, he or she uses *B* to support the gazing at *A*.

While there is no way to ascertain that CPC's recovery was related to his train viewing exercises, the timing of the recovery suggests this is a possibility. Prior to mid-January 2006 his average dizziness index persisted near or above 1.0 every day (Figure 2) for 15 months. The index falls to below 0.5 in mid-February, barely noticeable in mid March and totally resolved in May. During the training he felt that the supporting effect from *B* (stationary and uncomplicated environment) was critical to enable him to gaze at

A (fast optical flow – the moving train). We hypothesize that while his brain received two inputs from visual signals, one stationary (*B*) and the other moving (*A*), the "anchoring" or "supporting" effect means the stationary signal was being used to synchronize with the vestibular input. Eventually the brain adapted to this synchronization and learned to ignore the inappropriate visual conflicts.

4. Application on Condition Management

This theory may offer a significantly different concept compared to the conventional wisdom on how to manage car sickness. A passenger sitting in the front seat may be better able to minimize car sickness than in the back seat, partly because he is looking straight forward and exposed to slower optical flow than a rear passenger who is more affected by side views. However, the rear passenger has a larger area of *B* in the destabilizing potential because of the view of a larger portion of the car interior, so that the ratio of *A/B* is smaller. Indeed this has been a rather robust experience of the patient who, a few months after the onset of dizziness, was surprised to find out that he felt less dizzy sitting in the back than in the front, where used to prefer to sit prior to becoming sick.

This experience does not necessary contradict the common car sickness experience or theory. For non-visual vertigo passengers suffering from common car sickness, the *A/B* ratio mechanism may not apply. For visual vertigo patients, the *A/B* ratio mechanism has more effect; it may or may not offset the "common car sickness" mechanism. Whether dizziness is less sitting in front or in back would depend on the net offsetting of the two mechanisms. Apparently in the present case, the *A/B* ratio mechanism was often larger than the car sickness mechanism. There are three additional possibilities why this experience seems odd: First, most dizzy patients

probably automatically sit in the front, with few dizzy patients sitting in the back this

observation was less likely to be reported – and the few reports were likely discounted.

Second, patients with only intermittent visual vertigo but prone to car sickness may not

register because most of the time their dizzy feeling was from car sickness not visual

vertigo. Third, visual vertigo may not be related to a past history of motion sickness[1]. It is

therefore possible that car sickness involves conflicts between visual and vestibular

(and/or somatosensory) inputs while the patient's visual vertigo involves conflicts mainly

between different visual inputs (because vestibular input is mostly ignored).

The theory also explains a puzzling experience of the patient. He felt more

uncomfortable looking to the left than right while driving a car, and looking to the right

than left while sitting in the front passenger seat. The dizziness was less when he looked

to the opposite side of his seat because the inside of the car provided a larger B support.

The proposed theory also suggests a strategy for managing the visual vertigo

condition. If the ratio of A/B can be reduced the dizziness may be lessened. For

examples, the patient may want to wear a baseball or golf hat so that A is reduced and B

is increased through the sheltering of view above forehead by the bill (brim). This is

especially effective inside grocery stores where the optical perturbation from the higher

level structures and merchandises are blocked from view, replaced by the sight of the

stationary brim which also provides an anchoring effect. In a restaurant, indoor stadium,

train station or airport terminals the patient may choose to sit near walls, vertical

columns, or other fixed large structures to maximize B and reduce A. And if the patient is

not particularly prone to motion sickness, experimenting with sitting in the back of a car

without large rear swaying may be worthwhile. In addition, the theory also suggests a

strategy of reducing the destabilizing potential to manage the visual vertigo condition.

5. Summary

In this paper we propose a simple theoretical framework to train visual vertigo patients in which a visual anchor is used to re-weight sensory streams. This anchor can be incorporated inside a full surround field. The size and effects of the anchor can be gradually decreased and true full field can be introduced after successful treatment to ascertain the full recovery. The framework is in a way analogous to an inverse of the traditional gaze stabilization therapy. The patient is stimulated by a fast optical flow and uses a stationary noncomplex background as an anchor to overcome the destabilizing effect from the optical flow perturbation. The scheme can be adopted in many environments including looking at fast moving trains at increasing durations, or a screen image where several parameters (increasing t, increasing A/B, increasing V) can be increased. However, if on a screen it will be important to ensure that the B area will be truly non-perturbing because many patients reported difficulty of looking at computer screens.

The difficulty of reliably measuring visual dependence is a significant problem in diagnosing, monitoring and treating visual vertigo. The destabilizing potential DP or TDP proposed here may be used as a parameter to gauge the degree of visual dependence. A picture-in-picture image (Figure 3b) may be incorporated into a posturography system with the A/B ratio or V velocity variable to assess the degree of visual dependence quantitatively. This can facilitate monitoring the progress and the effectiveness of the treatment. The proposed scheme is based on one patient's experience, but the simplicity of the framework should allow easy design of control trials to test its effectiveness.

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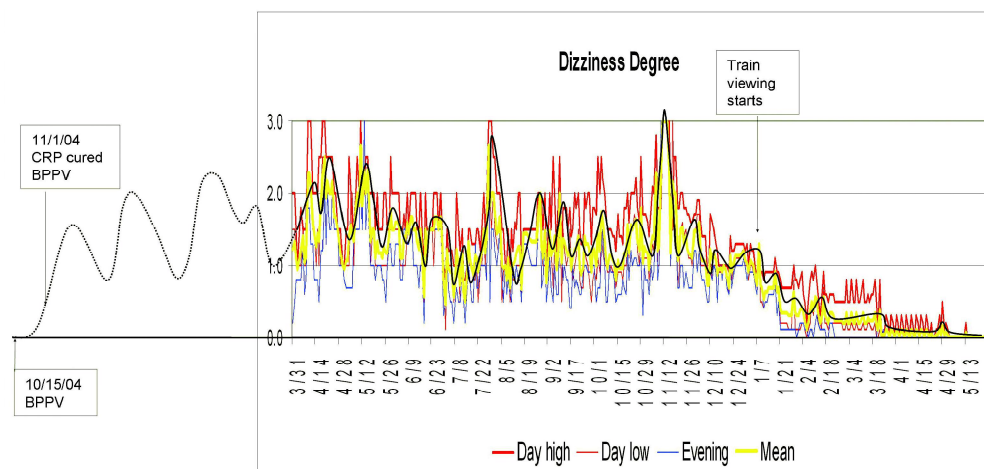Telephone: 831-656-2840; fax: 815-371-5444. cpchang@nps.edu

Figure Legends

Figure 1. Schematic figure to show the contrasts of two background scenarios with the same optical perturbation. The Destabilizing Potential as introduced later in the text is large for the left panel and small for the right panel.

Figure 2. Time series of the daily dizziness index of the patient, recorded at night of each day starting March 31, 2005. Values below 1.0 indicates mild dizziness, value 3.0 indicates severe dizziness including oscillopsia. The thick lines are a smoother version of the daily mean, with the dotted line covering the period October 15, 2004 – March 30 2005 constructed after the fact based on memory of major events.

Figure 3. (a) Parameters determining the destabilizing potential. Colored area indicates visual perturbation. (b) Gaze Stabilization for vestibular rehabilitation. Colored area indicates visual perturbation.

Schematic figure to show the contrasts of two background scenarios with the same optical perturbation. The Destabilizing Potential as introduced later in the text is large for the left panel and small for the right panel.
214x114mm (600 x 600 DPI)

Dizziness Degree

11/1/04
CRP cured
BPPV

Train
viewing
starts

10/15/04
BPPV

— Day high — Day low — Evening — Mean

10/15/04-3/30/05 based on
memory of major events

3/31/05→5/31/06
based on daily entries

Time series of the daily dizziness index of the patient, recorded at night of each day starting March 31, 2005. Values below 1.0 indicates mild dizziness, value 3.0 indicates severe dizziness including oscillopsia. The thick lines are a smoother version of the daily mean, with the dotted line covering the period October 15, 2004   March 30 2005 constructed after the fact based on memory of major events.
260x163mm (600 x 600 DPI)
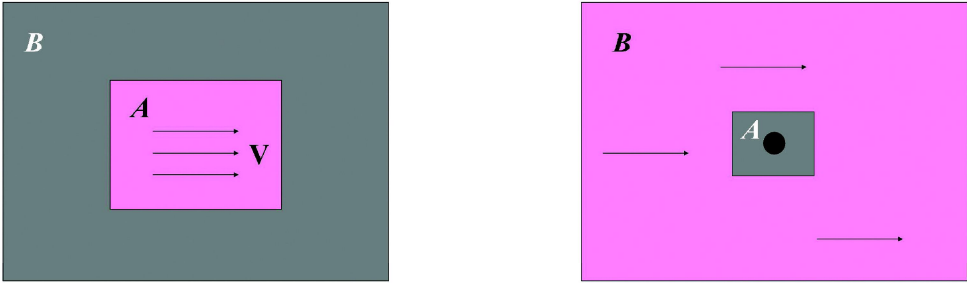
(a) Parameters determining the destabilizing potential. Colored area indicates visual perturbation. (b) Gaze Stabilization for vestibular rehabilitation. Colored area indicates visual perturbation.
222x70mm (600 x 600 DPI)